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THE PLACE OF THE NUMERICAL PROBLEM IN HIGH-SCHOOL PHYSICS

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The trend of modern education in the development of high-school curricula has been away from the domination so long exercised by college-entrance requirements, and rightly so. In the subject of physics this tendency has taken form in a so-called "dematematization" of the subject—an expurgation of the more involved mathematical proofs and conceptions, and the substitution of a more descriptive, qualitative method of treatment for the earlier, quantitative method. How far this process should be carried, and at what point a proper balance obtains between descriptive and quantitative methods, is still unsettled. In the solution of this question, the first inquiry to be made is the extent to which the present teaching accomplishes its purpose in securing a thorough grasp of the underlying principles of the subject. This paper will attempt to give a solution to this problem as far as the subject of mechanics is concerned, a subject in which of necessity, if it is to be taught at all, the quantitative or simple numerical problem must have a greater emphasis than in any other branch of elementary physics. This paper presents the results of a simple test in mechanics, in which the problems are so chosen that they satisfy the following requirements: (1) they cover the ground of the usual high-school course in mechanics; (2) they range from simple to fairly complex problems; (3) they require only the very simplest arithmetical calculations, thus reducing mechanical errors to the minimum.

The test blanks with the instructions given to the subjects are shown below.

PHYSICS TEST. MECHANICS

Name....................................Date....................
School..................................Class...................
Age......Sex......How many weeks have you studied mechanics?......
Fill out the above blanks first.

You will be allowed exactly 40 minutes for this test. Do as many of the problems as possible in that time; do them in any order. When you have the final answer, write it in the space provided, being careful to state not only the numerical answer, but also the proper unit (e.g., 15 lbs., 15 ft. per sec., or whatever the unit may be). All calculations should be done on loose sheets.

No questions may be asked regarding any of the problems.

Answer

1. A grocer has a platform balance, the ratio of the arms of it being as 9 is to 10. If he weighs out 20 lbs. of sugar to one man, putting it on the right pan, and 20 lbs. to another, putting it on the left pan, how much sugar will he save or lose in the two transactions? 1. ....
2. A man weighing 150 lbs. stands on one end of a railroad rail 30 ft. long, which then balances over a fulcrum at a point 3 ft. from its middle. What is the weight of the rail? 2. ....
3. How many lbs. of water can be pumped per minute from a mine 500 ft. deep by an engine expending 20 horsepower? (1 h.p. = 550 ft. lbs. per sec.) 3. ....
4. A dam is 50 ft. long and 20 ft. high, and the water just reaches the top. What is the total force against the dam? (1 cu. ft. of water weighs 62.4 lbs.) 4. ....
5. The water-level in a tank on top of a building is 150 ft. above the ground. What is the pressure in lbs. per sq. in. at a faucet 6 ft. above the ground? (1 cu. ft. of water weighs 62.4 lbs.) 5. ....
6. A motor-boat weighs 9,000 kg. What must be the volume in cubic meters of the underwater portion of its hull? 6. ....
7. How deep must an inverted open bottle be sunk in water in order to reduce the contained air to one-third its initial volume? (Take barometric height = 75 cm. and density of mercury = 13.6.) 7. ....
8. The density of oxygen at 0 degrees and 1 atmosphere pressure is 0.00143 gm. per cc. A 100-liter tank contains 715 gm. of oxygen; under what pressure is it at 0 degrees? 8. ....
9. A stream 1 mile wide is flowing 4 miles per hr. A man rows 5 miles per hr. How long will it take him to row straight across? 9. ....
10. A boy is able to exert a force of 75 lbs. How long a plank (inclined plane) must he have in order to push a 350-lb. truck up to a doorway 3 ft. above the ground? 10. ....

Answer

11. A train starts from rest. At the end of 5 min. its velocity is 45 ft. per sec. What is its average acceleration in ft. per sec.? 11. ....

12. A bullet is fired vertically upward from a gun. What must be its muzzle velocity in order that it shall rise 10,000 ft.? (g.=32 ft. per sec.) 12. ....

13. A 3,200-lb. automobile starting from rest attains a speed of 90 ft. per sec. in 30 sec. What is the average force in lbs. exerted by the engine? 13. ....

14. A pile is to be driven into ground which resists penetration with a force of 15,000 lbs. How far will it be driven at each blow of the 320-lb. ram of a pile-driver moving with a velocity of 30 ft. per sec.? 14. ....

The foregoing test was applied to 238 pupils in four typical high schools in a city system representative of distinctly progressive educational methods. Any conclusions drawn as a result of this study may therefore be taken as representative of the general condition. Of the 238 subjects, 165 were boys and 73 were girls. The average age was sixteen and one-half years. All had studied mechanics within the year, devoting on the average 60 periods to class work and 48 periods to laboratory (a period representing 40 minutes of work). The test was administered without previous warning in a single 40-minute period, no questions being permitted. The results are shown in Table I.

When we examine the combined results of the four schools, taking the whole body of pupils, it will be seen that on the average each problem is successfully solved by only 15 per cent of the pupils; no problem is solved by more than 69 per cent, while two straightforward problems are out of the range of every pupil. This reveals a condition truly surprising. The extent of the lack of comprehension shown therein of the numerical relations of the simplest and most fundamental principles of physics is certainly startling, and lends support to the criticism often heard that the average high-school student of physics acquires merely a mass of disconnected facts, with little notion of the underlying and unifying principles. It is clear that the present method of teaching physics fails in its object in so far as it attempts to give the pupil any knowledge of the principles which lie back of common numerical problems.

TABLE I

School	No. of Pupils	Number of Problem																													
		1		2		3		4		5		6		7		8		9		10		11		12		13		14		Mean	
		Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right	Attempts	Right
		Percentage																													
A......	65	83	18	95	6	97	54	94	26	72	8	54	26	48	8	42	9	51	6	92	77	74	18	54	37	28	...	20	...	65	21
B......	59	80	22	78	...	88	46	93	25	66	17	53	17	36	2	37	5	59	3	87	80	24	3	12	...	22	...	29	...	55	16
C......	54	74	35	82	...	80	35	69	4	50	13	7	6	13	...	22	...	61	7	82	61	54	13	31	4	30	...	20	...	48	13
D.....	60	92	32	87	2	75	33	80	3	58	7	30	7	25	...	22	5	70	3	83	58	43	...	13	...	33	...	22	...	52	11
Total	238	82	26	86	2	85	42	84	15	62	11	37	14	31	3	31	5	60	5	86	69	49	9	29	11	28	...	23	...	55	15
P.E. equivalent for each problem.....		0.95		3.05		0.30		1.55		1.80		1.60		2.80		2.45		2.45		0.75		2.00		1.80		....		....		....	

Haziness and guesswork in the realm of the exact are the forerunners of lack of appreciation of, or even contempt for, scientific method. In the opinion of the authors, if anything worthy of the name of physics is to be taught, this process of making the subject attractive and easy by de-mathematizing it must cease; for, in attempting to eliminate the excessive growth of algebraic formulae, we have already dangerously weakened the sustaining framework of fundamentals. We seem to have confused the application of simple, numerical, quantitative relationships with the verification of rigorous, abstract, mathematical deductions and conceptions. Physical science is essentially a matter of relationships; and it is in the building up of these relationships that the chief interest as well as the chief value of its study lies. In seeking to increase the interest content of our subject, let us not overlook this point. The average pupil is never so enthusiastic a student of science as when he has correctly "figured out" the result of a given set of conditions. Quantitative measurement in the laboratory is the universal practice, and should naturally be supplemented at every step with numerical problems, to the more vital correlation of classroom and laboratory interests. Formulae learned by rote are the bugbear of every teacher of physics; but formulae as the shorthand expression of thoroughly understood general principles or relationships are the mightiest supports to sound physical reasoning. And finally, for the inculcation of exact thinking, it is not sufficient to learn the "why" and "how" to a given phenomenon, but also the "how much," to be able to judge the relative effects of interacting causes, to separate the more important from the less, and to estimate the result with some degree of precision.